Spectrophotometric Determination of Hydroxyurea and Stability in Nitric Acid Medium

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Abstract

A spectrophotometric method has been developed for the determination of hydroxyurea. The methodology involves the reduction of standard potassium permanganate ($KMnO_4$) prepared in 1N sulfuric acid medium by hydroxyurea (HU). $KMnO_4$ is having λmax at 525 and 545 nm. The decrease in absorbance for a given $KMnO_4$ solution by the addition of HU is compared to the solution without HU having the same concentration of $KMnO_4$. Molar absorption coefficient (ε) value is found to be 957 mol^{-1} L cm^{-1} with a precision of 3.8%. The correlation coefficient was 0.9975. The linear dynamic range of this method was found to be 10 to 80 ppm of HU. Effect of acidity and temperature on the stability of HU in nitric acid medium was also studied. Acid dependence on radiation effect of HU solution and dose dependence of stability of HU solution were also studied.

Keywords

Hydroxyurea; Stability; Radiation Stability; Nuclear Fuel Reprocessing; Spectrophotometer

Introduction

Hydroxyurea is commonly known as Hydrea and is widely used in the medical field for various applications. It is used as an antineoplastic agent (used to treat cancer) and also used in the management of thrombocytosis which is a condition in which platelet levels are abnormally high. Hydroxyurea is used as a drug in the treatment of sickle cell anemia also it is believed to inhibit human immunodeficiency virus 1 (HIV-1).

Hydroxyurea can be used as an alternate partitioning agent during the reprocessing of spent fuel from fast reactor. Spent fuel from Fast reactor is being processed by modified PUREX process using 30% TBP as extractant [R. Natarajan, IANCAS Bulletin]. It involves two co extraction cycle and one partitioning cycle. During partitioning, Uranium and Plutonium is separated from each other by various reagents such as Ferrous sulphamate [Kjeller Report], Hydroxylamine nitrate [S.L. Yarbro, JRNC,Vol 235], [G.L. Richardson], Uranous stabilized with hydrazine [P. Siva Kumar, NUCAR 2009], Electrolytic partitioning [IGC Newsletter] etc., Each of the process is having inherent disadvantages such as generation of corrosive wastes or slow kinetics especially in high acid medium or requirement of large quantities of uranous or fouling of the electrode etc. Our earlier studies show that HU can be used as a partitioning agent for the separation of plutonium from uranium [P. Sivakumar JRNC, Vol 291] [P. Sivakumar JRNC, Vol 292]. It has been reported that HU, a salt free reducing agent can be used to reduce Pu^{4+} to Pu^{3+} without affecting UO_2^{2+} in the re-processing of spent nuclear fuel [Zhu Zhaowu, JRNC, Vol. 260], [Zhu Zhaowu, JRNC, Vol. 262]. It is well known that HNO_2 present in nitric acid interferes in the partitioning cycle by oxidising Pu^{3+} to Pu^{4+}. HU destroys HNO_2 and hence stabilizes Pu^{3+} in the process stream. HU concentration and stability in the process stream plays vital role for the efficient partitioning of U and Pu. The reported method for the colorimetric determination of HU [Boyland and R.Nery, Analyst, Vol 89], [Boyland and R.Nery, J.Chem.Soc.(C)] needs the preparation of trisodium pentacyanamine ferrate (II) complex. In phosphate buffer at pH 7.5 hydroxyurea and dihydroxyurea forms coloured complex with pentacyanoferrate (II) complexes, $Na_3[Fe(CN)_5X]$ where X is a molecule of hydroxyamino derivative. The complex shows maximum absorbance at 465 nm which correspond to concentration of HU when X is hydroxyurea. Since the reported method is cumbersome, a method is developed for the

determination of HU. Permanganate prepared in neutral and 1M NaOH medium shows brown color precipitate on addition of hydroxyurea and hence not suited for the analysis of hydroxyurea.

In the present method, determination of HU is carried out by its oxidation with potassium permanganate in acidic medium. The decrease in colour intensity of permanganate as a function of HU concentration is measured at 525 nm. Since HNO_3 is used as a medium in the process stream, the stability of HU in nitric acid medium is also studied. Radiation stability of HU is also carried out with respect to acid concentration and radiation adsorbed dose. The detail of the study is presented in this paper.

Experimental Part

Solution Preparation

Standard Potassium permanganate of 8000 ppm is prepared in 1N H_2SO_4. 1000 ppm of Hydroxyurea (Himedia, minimum assay 98% purity) prepared in water. Hydroxyurea of 7.6 gpl and 8 gpl were prepared in water, 1N, 2N, 3N and 4N nitric acids to find out the stability and thermal stability of HU in that medium respectively.

Instrumentation

Ocean optics USB-4000 spectrophotometer with 10mm path length cell is used for absorption spectra measurement.

Gamma chamber-900 is used to irradiate the HU solution.

Absorbance Spectra Measurement

Standard Potassium permanganate solution is taken in a cell and absorbance spectrum is taken in the wave length range of 250 nm to 750 nm. Potassium permanganate is mixed with different mole ratio of HU and absorbance spectra are taken again.

Estimation of Hydroxyurea

Standard potassium permanganate of 800 µg (5.063 µ mole) was taken in nine 10 ml standard measuring flasks (smfs). To this 0 to 950 µg (0 to 12.5 µ mole) of hu was added. The mixture was shaken well and made up to the mark with water. The absorption spectrum was taken each time and the results are in fig.1. potassium permanganate show characteristic peaks at 525 and 545 nm. The decrease in absorbance values by the addition of hu can be measured either at 525 nm or

545 nm. The decrease in absorbance values by the addition of different mole of hu were measured at λmax of 525 nm and the results are in Table I. Since known amount of HU is added to known amount of $KMnO_4$, residual amount of $KMnO_4$ and the ratio of HU to initial $KMnO_4$ can be calculated and the values are also included in Table I. A graph was drawn by taking ratio of concentration of HU added to initial $KMnO_4$ on X axis and the residual $KMnO_4$ concentration on Y axis and is shown in Fig.2. A calibration plot is drawn by taking the decrease in absorbance values as a function of HU and the results are in Fig.3.

TABLE I REDUCTION OF STANDARD POTASSIUM PERMANGANATE BY HYDROXYUREA

| $KMnO_4$ µmoles	HU µmoles	Absorbance	Difference in Absorbance	ε mol $^{-1}$ L cm $^{-1}$	Residual $KMnO_4$ µmoles	HU added/Initial $KMnO_4$
5.063	0.00	1.125			5.063	0.0
5.063	2.63	0.862	0.263	999	3.880	0.5
5.063	3.95	0.730	0.395	1001	3.286	0.8
5.063	5.26	0.620	0.505	960	2.790	1.0
5.063	6.58	0.488	0.637	968	2.196	1.3
5.063	7.89	0.356	0.769	974	1.602	1.6
5.063	10.53	0.152	0.973	924	0.684	2.1
5.063	11.84	0.022	1.103	931	0.099	2.3
5.063	12.50	0.002	1.123	898	0.009	2.5
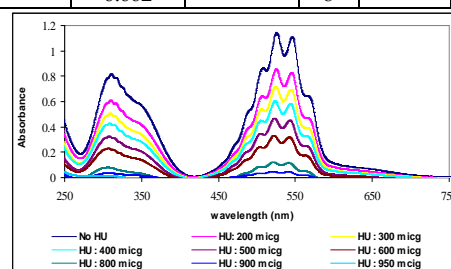
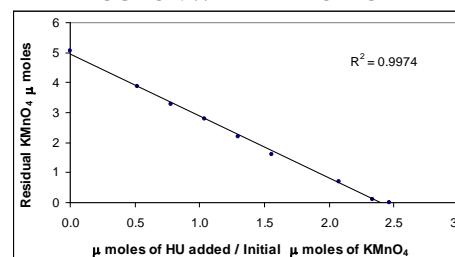FIG. 1 ABSORPTION SPECTRA OF PERMANGANATE REDUCTION WITH HYDROXYUREA

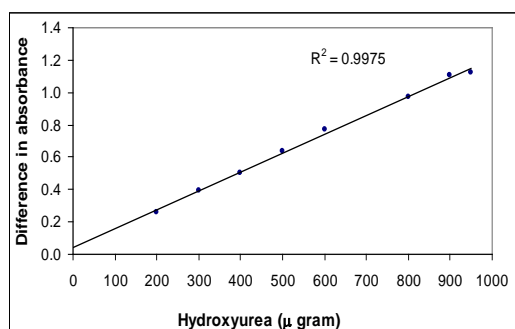FIG.2 STOICHIOMETRY OF HU REQUIREMENT FOR KMNO4 REDUCTION

FIG.3 CALIBRATION PLOT OF HU OXIDATION WITH
PERMANGANATE

Stability of HU in Nitric Acid Medium as a Function of Time

Hydroxyurea of 0.1M (7.6 gpl) is prepared in water, 1N, 2N, 3N and 4N nitric acid and diluted with water at the time of analysis. Standard potassium permanganate in 1N sulfuric acid medium taken in 10ml SMFs is reduced with HU prepared in different molarity of nitric acid. The content of the SMFs were shaken well and made up to the mark with water. The decrease in absorbance values were measured at 525 nm after 6, 24 and 48 h. From this, stability of the hydroxyurea is calculated and the results are given in Fig.4. Reagent blank is prepared by diluting the corresponding acid with water.
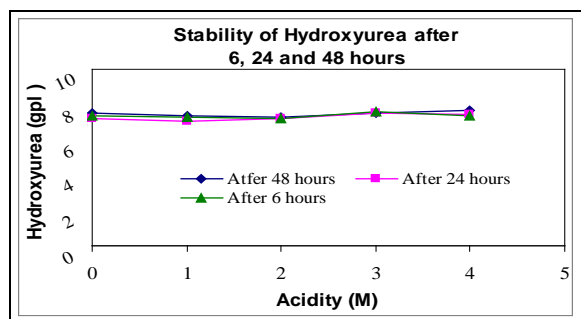

FIG. 4 STABILITY OF HYDROXYUREA IN NITRIC ACID AS
FUNCTION OF TIME

Thermal Stability of Hydroxyurea Solution

In order to find the applicability of HU as a reducing agent in Improved Plutonium Uranium Reduction Extraction (IMPUREX) process, which involves high temperature flow sheet, HU stability is evaluated as a function of temperature. This study is essential since the radioactive decay adds heat to the solution. A known concentration of HU (around 8 g/L) is prepared at different acidities. 10 ml of these solutions are taken in a closed vial to avoid evaporation losses and heated in a water bath containing thermostat provision. Temperatures of the hydroxyurea solution are also

checked by a thermometer. Solutions are heated to the required temperature for the period of 30 minutes and the samples were withdrawn. The samples were allowed to cool and analysed for HU concentration by potassium permanganate method and the results are shown in Table II.

Radiation Stability of Hydroxyurea

Radiation stability of Hydroxyurea solution was found by preparing known concentration of HU in 1 and 4 N nitric acids and irradiated from 0.5 to 10 Gray. The solution was analysed after each irradiation. The results are shown in Fig.5 where HU concentrations are plotted against the radiation absorbed dose.

TABLE II THERMAL STABILITY OF HYDROXYUREA IN NITRIC
ACID SOLUTIONS

Acidity	HU (g/L) (after heating)				
	25° C	35° C	50° C	60° C	70° C
0	8.25	8.06	8.06	8.13	7.94
1	8.13	7.98	7.90	7.90	7.94
2	7.81	7.92	8.04	7.62	7.81
3	7.70	7.77	7.81	8.04	8.04
4	7.83	7.87	7.79	7.90	7.83

The effect of gamma radiation on HU solution prepared at 0, 1, 2, 3 and 4 N nitric acids were carried out with the irradiation level of 10 Gray. The solutions are analysed before and after irradiation and the results are shown in Fig.6 by plotting HU concentration on Y axis and nitric acid molarity on X axis.
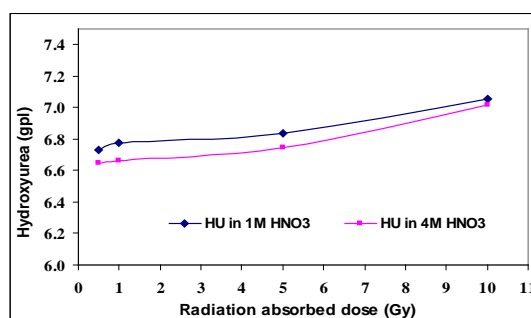

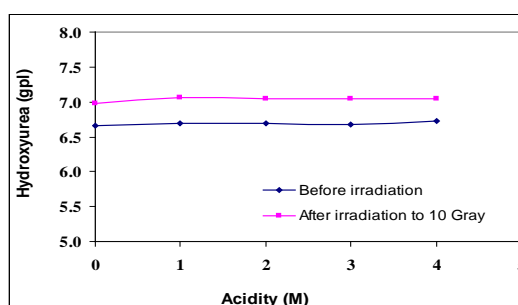FIG. 5 DOSE DEPENDENCE ON STABILITY OF HU SOLUTION

FIG.6 ACID DEPENDENCE OF RADIATION STABILITY OF HU
SOLUTION

Results and Discussions

Permanganate solution prepared in neutral and 1M NaOH medium shown brown color precipitate which may be due to the reduction of $KMnO_4$ to MnO_2 by the addition of hydroxyurea and hence is not suited for the analysis of hydroxyurea. Data in Fig.1 indicates that initial 525 nm peak corresponding to $KMnO_4$ is decreased by the addition of HU and the decrease is linear with respect to HU concentration. This decrease in absorbance is attributed to decrease in the concentration of $KMnO_4$ due to its reaction for oxidizing hydroxyurea. The stoichiometric requirement of HU/$KMnO_4$ is studied and the results are given in Table 1 and Fig.2. Data in Table 1 indicates that molar extinction coefficient value is 957 mol^{-1} L cm^{-1}. Data in Fig.2 indicates that the stoichiometric requirement of HU oxidation with $KMnO_4$ is 2.5. From the stoichiometric ratio of HU: $KMnO_4$, the predicted redox reaction can be written as

$$2MnO_4^- + 5NH_2CONHOH + 12H^+ \rightarrow 2Mn^{2+} + 6NH_4^+ + 5 CO_2 + 4 H_2O + 2 N_2O + O_2$$
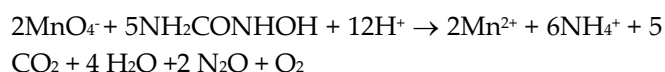
The difference in absorbance values of $KMnO_4$ as a function of HU is given in Fig.3. Data in Fig.3 shows that the curve is linear and the regression coefficient is found to be 0.9975 and hence HU can be analyzed by this method. The ranges of HU that can be estimated by this method vary depending upon the concentration of permanganate solution initially taken for analyses. By taking 800 µg (5.06 µ mole) of $KMnO_4$, the amount of HU that can be determined by this method was 100-800 µg in 10 ml SMF.

Data in Fig.4 show that there is no appreciable change in HU concentrations at different acidities even after 6, 24 and 48 h. It is anticipated that some amount of HU should have been destroyed by nitrite ion present in nitric acid and hence there would be decrease in the concentration of HU in nitric acid medium. Since the concentration of HU taken for the study is appreciably high (0.1M HU which corresponds to 7600 ppm) there is no much variation in HU concentration with respect to acidity and time despite a small amount of HU might have been consumed by nitrite ion. The variations of the concentration of HU are only ± 5%. This results shows that HU is stable in nitric acid medium over a period of time.

Data in Table 2 indicates that concentration of HU is not significantly affected with respect to temperature. The variation in the concentration of HU is only ± 5%. This shows that HU is thermally stable over the temperature range we have studied.

The data shown in Fig.5 indicates that there is a slight increase in the concentration of HU with respect to irradiation. This is due to slight increase in DA values (DA values is the difference in absorbance values of $KMnO_4$ with and without HU) as a function of gamma irradiation. This slight increase in DA values (HU concentration) with respect to gamma irradiation may be due to the destruction of $KMnO_4$ by the free radicals or H_2O_2 formed by irradiation of HU solution prepared in nitric acid medium. Free radicals may be formed from the radiolysis of nitric acid or radiolysis of HU. Increase in radiation level would have produced more free radicals or H_2O_2 and hence there is increase in the DA values as a function of gamma irradiation. The increase is not much pronounced up to 5 Gray and is slightly more at 10 Gray. Even if we assume that the free radicals are formed from the radiolysis of HU, there is only 5% increase in absorbance and hence it may concluded that HU is not decomposed due to gamma irradiation.

The data shown in Fig.6 indicates that there is a slight increase in the concentration of HU solution prepared in 0, 1, 2, 3 and 4 M nitric acid medium on irradiation to 10 Gray. This is due to slight increase in DA values before and after irradiation of HU solution which results in increase in the concentration of HU. This may be due to the destruction of some of the $KMnO_4$ by free radicals or H_2O_2 formed by irradiation of HU solution which causes increase in DA values. The slight increase in DA values would have been due to the destruction of $KMnO_4$ by the free radicals or H_2O_2 formed by gamma irradiation of nitric acid or HU solution. If HU is decomposed by gamma irradiation, then there should be decrease in DA values and hence there should be decrease in the concentration of HU. The data given in Fig.6 show that there is 4-5 % increases in the concentration of HU solution prepared in 0, 1, 2, 3 and 4 M nitric acid on irradiation. Even if we assume that the free radicals are formed by the radiolysis of HU, there is no much decomposition of HU, because there is only 5% increase in the concentration. The results of irradiation of HU solution prepared in 0, 1, 2, 3 and 4 M nitric acid medium shows that HU solution is not greatly decomposed by gamma irradiation.

Conclusion

Hydroxyurea, a promising salt free reducing agent, employed for the reduction of Pu in nitric acid

medium can be analysed by the oxidation with permanganate in sulfuric acid medium. This is a simple redox reaction and the ε value is found to be 957 mol $^{-1}$ L cm^{-1}. The HU solution is stable in nitric acid medium over a period of time. Stability of HU is also not affected by the temperature range studied. Gamma irradiation experiments indicate that HU solution is not greatly decomposed by gamma irradiation levels upto 10 Gray irrespective of the acidity of the solution.

ACKNOWLEDGEMENT

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